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# Biomechanical properties of plate constructs for feline ilial fracture gap stabilization

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Abstract: OBJECTIVE: To determine the biomechanical properties of plating techniques for comminuted feline ilial fractures. STUDY DESIGN: Ex vivo study on 40 paired feline hemipelves. SAMPLE POPULATION: Forty paired fresh-frozen hemipelves that had been collected from 20 cats aged 2-6 years and weighing 4.0-5.5 kg. METHODS: A transverse 3-mm gap was created in each ilium. Hemipelves were fixed with one of the following methods (n = 10 per group): (1) a dorsal plate and nonlocking screws, (2) a lateral plate and nonlocking screws, (3) a lateral plate and locking screws, or (4) a lateral and dorsal locking compression plate using nonlocking screws. Each specimen was subjected to incremental, sinusoidal cyclic loading until failure, defined as 10-mm displacement. The initial stiffness and number of cycles required to reach 1-, 2-, 5-, and 10-mm axial displacement were statistically analyzed. RESULTS: The initial stiffness and number of cycles to failure were higher in specimens fixed with double nonlocking plates than in all other fixations ($P < .05$) except specimens fixed with lateral locking plate at 10-mm displacement ($P = .44$). Locking implants withstood more cycles to 5- ($P < .05$) and 10-mm ($P < .05$) displacement compared with other single-plate nonlocking groups. Screw loosening occurred only in the 3 nonlocking fixations. CONCLUSION: Double plating improved stiffness and resistance to failure of comminuted feline ilial fracture constructs compared with all other fixations. Single locking plates produced superior constructs compared with single nonlocking constructs. CLINICAL SIGNIFICANCE: Locking implants are recommended to repair comminuted feline ilial fractures for their extended fatigue life and resistance to screw loosening. Orthogonal plating offers a strong nonlocking alternative.

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**Title**

Ex vivo biomechanical properties of plate constructs for feline ilial fracture gap stabilization.


**Abstract**

**Objective:** to evaluate biomechanical properties of different plating techniques for comminuted feline ilial fractures in a cadaveric model.

**Study Design:** *Ex vivo* cadaveric study.

**Methods:** Forty paired feline hemipelves were used. A transverse 3 mm gap was created in each ilium. Hemipelves were fixed with one of the following methods (n=10 per group): 1) a dorsal plate using non- locking screws; 2) a lateral plate using non-locking screws; 3) a lateral plate using locking screws; 4) a lateral and dorsal LCP using non-locking screws. Each specimen was subjected to incremental, sinusoidal cyclic loading until failure, defined as 10 mm displacement. Initial stiffness and number of cycles needed to reach 1, 2, 5, and 10mm axial displacement were statistically analyzed.

**Results**: Initial stiffness and number of cycles to failure were higher in the group with double non-locking plates compared with all other groups ($p<0.05$), except for the group fixed with a lateral locking plate, which was not different from the double plate group for 10mm displacement ($p=0.44$). Locking implants withstood more cycles to 5 ($p<0.05$) and 10mm displacement ($p<0.05$) compared to the other single plate non-locking groups. No screw loosening occurred in the locking constructs, while it was observed in all three non-locking groups specimens.

**Conclusion:** Double plating results in significantly higher stiffness and resistance to failure compared to all other groups in a comminuted feline ilial fracture model. Single locking plates showed superior results compared to single non-locking constructs.

**Clinical significance:** Due to the increased fatigue life and resistance to screw loosening locking implants are recommended in comminuted feline ilial fractures. When non locking implants are used, orthogonal plating offers a strong fixation method.

## Introduction

Ilial fractures are a common finding in cats that experienced trauma.[1,2] Retrospective studies evaluating pelvic fractures in cats found the ilium to be involved in up to 50% of cases.[2,3] Reported indications for surgical repair of pelvic fractures include involvement of the weight-bearing axis, acetabular fractures, neurologic deficits and excessive pain.[4-7] Lateral plating is the most common method of repair of ilial fractures in cats.[4,5] However, the thin ilial bone offers only limited screw purchase in lateral plating, leading to a high frequency of screw loosening and pelvic canal narrowing due to loss of reduction.[4] Narrowing of greater than 45% of the pelvic canal has been reported to be a risk factor for difficulties in passing feces. Obstipation, constipation and progression to megacolon may necessitate further invasive therapy.[2] The risk of screw loosening and its associated complications may be increased in comminuted ilial fractures. An alternative technique is dorsal plating, which allows greater screw purchase and is associated with a lower incidence of screw loosening.[5] However, this technique is technically demanding and may have greater risk of iatrogenic nerve damage.[5,8] Another approach to decrease the risk of screw loosening associated with lateral plating is to use locking implants. Locking plates have been recommended in human patients with osteoporotic bone, providing a rigid screw-plate interface leading among other beneficial factors to less screw loosening.[9] The advantage of locking screws may also be apparent in the fixation of the feline ilium, because its thin cortices may increase the risk of screw loosening. In a recent retrospective study comparing different methods of fixation of ilial fractures in cats, a 50% incidence of screw loosening was found in cases treated with non-locking plates in contrast to no screw loosening in the group treated with locking plates. [10]

Although some biomechanical studies evaluating fixation constructs for ilial fractures in small animals have been published,[8,11,12] it is unclear whether locking plate constructs offer a mechanical advantage over non-locking plating techniques in feline ilial fractures. Although double plating has been successfully reported for comminuted ilial fractures in cats,[10] the biomechanics of orthogonal plating using non locking implants in comminuted fractures of the ilium have so far not been evaluated. Therefore, the purpose of this study was to compare the biomechanical properties of different plating techniques in a fracture model simulating a comminuted ilial fracture in cats. We hypothesized that 1) constructs with combined lateral and dorsal plating are significantly stiffer and more resistant to cyclic fatigue than single plating constructs and 2) constructs with a single lateral locking plate have a significantly higher construct stiffness and load to failure compared to the single plate non-locking constructs.

## Materials and Methods

*Specimens Procurement and Preparation*

A total of 40 paired fresh-frozen hemipelves were collected from 20 cats with a mean age of 4.5 years (range 2-6 years) weighing 4.0-5.5 kg and euthanized for reasons unrelated to this study. Cats with endocrinopathies, renal disease, or long term treatment of glucocorticoids prior to euthanasia were not included in the study. Owner consent was obtained for all animals used in this study. Ventrodorsal and mediolateral pelvic radiographs were taken to exclude bone pathology and to select specimens of similar size. For this purpose, the size of each pelvis was determined by measuring the ilio-acetabular length (IAL) defined as the distance from the cranial border of the acetabulum to the most cranial aspect of the border of the ilial wing as measured on mediolateral radiographs. Only specimens exhibiting an IAL of 4.8 ± 0.48 cm were included. [4,10]

The pelvis, sacrum and the seventh lumbar vertebra (L7) were isolated from each cat. Soft tissue was removed while leaving ligamentous and cartilaginous structures intact. Specimens were subsequently wrapped in saline-soaked gauzes and stored at -20° until testing. Prior to biomechanical testing, specimens were thawed for 24 hours at room temperature.

*Construct Preparation*

For manipulation and orientation purposes, a 1.0mm Kirschner wire was placed transversely across the ischial tubercles in the intact pelvis (with the wire being oriented parallel to the horizontal plane). After placement of the Kirschner wire its central part was removed with a pin cutter and the hemipelves were separated with an oscillating saw. Using the Kirschner wire as a reference point, the ilium was oriented in 20° external rotation during potting to mimic the *in vivo* orientation of the pelvis during testing.[8] A 3mm gap was created starting 10mm cranial to the most cranial aspect of the acetabulum to simulate a comminuted ilial fracture. A partial ostectomy through the lateral dorsal and ventral cortices was performed using an oscillating saw with a 0.4mm blade (XXX) leaving only a thin bridge of bone on the medial aspect in order to maintain alignment. Each hemipelvis was plated with 2.0mm Locking Compression Plates (LCP, Synthes, XXX) with different combinations of screw type (locking or non-locking screws) and plate position (dorsal, lateral or combination). The ostectomy was completed after plate application.

*Testing groups*

According to a computer generated table, each hemipelvis was randomly assigned to one of the following fixation groups (Fig 1): group 1: a 6-hole 2.0mm Locking Compression Plate

(LCP) fixed with non-locking screws to the lateral aspect of the ilium (LatLCPnl); group 2: a 6-hole 2.0mm LCP fixed with locking screws to the lateral aspect of the ilium (LatLCPl); group 3: a 6-hole 2.0mm LCP fixed with non-locking screws to the dorsal aspect of the ilium (DorsLCPnl); group 4: one 6-hole (lateral) and one 4-hole (dorsal) 2.0mm LCP fixed with non-locking screws to the lateral and dorsal aspects of the ilium, respectively (DoubleLCPnl).

When applying a lateral plate, the middle of the three cranial screws was inserted into the sacrum, at a depth of approximately 50% of the total sacral width. An aiming device (Veterinary instruments, Sheffield, UK) was used to standardize the central position of the sacral screw in the body of the sacrum in all specimens. In the LatLCPl group the sacral screw was placed as the first screw in order to maintain the central screw position with the fixed screw orientation. For the dorsal plate, a single 2.0mm screw was inserted into each of the cranial and caudal fracture segments in the first and fourth hole of the plate, thereby avoiding interference with any other screw.

All implants were inserted according to AO principles by two experienced board certified surgeons (XXX, XXX). Each cortical screw was tightened with two fingers, while the locking screws were tightened at a torque of 0.4Nm (Synthes LCP 2.0 recommendation) with a torque limiter screwdriver.

Following plating, the ilial wing and the sacrum were potted in PMMA so that 10mm of the cranial end of the ilium and L7/sacrum were embedded. Additional K-wires were inserted into the cranial aspect of the specimen to increase the interface between the specimen and the polymethylmethacrylate (PMMA). To avoid incorporation of the plate in the PMMA, clay was placed around the implants before potting. The ilium was oriented with its long axis parallel to the potting cylinder to standardize its position. After potting, the modeling clay was removed and an adequate free margin of ≥ 3mm around the plate was confirmed.

*Biomechanical testing*

Prior to biomechanical testing, all screws were tightened. Biomechanical testing was performed on a servo-hydraulic test system 858 Mini Bionix (MTS Systems, Eden Prairie, MN) equipped with a 4kN/100Nm load cell. Each specimen was tested in a cantilever bending setup (Fig 2). The PMMA cylinder was mounted in a fixation device while orienting the hemipelvis horizontally and with an external rotation of 20° as determined with the orientation wire.[8] Specimen positioning was confirmed by the use of a goniometer. The specimen was rotated so that the acetabulum was facing up (Fig 2). The acetabulum was loaded in compression using a 9.5mm diameter custom rod, simulating the femoral head, attached to the machine transducer and a load cell.

All specimens were biomechanically tested according to previously published protocols.[13,15] Each specimen was subject to sinusoidal cyclic loading at 2Hz. Keeping the valley load of each cycle at a constant level of 5N throughout the test, the peak load was started at 10N (20% body weight) and was progressively increased at a rate of 0.01N/cycle until the test stop criterion 10mm axial displacement of the machine transducer was reached.

Such loading aims to achieve construct failure independently of specimens' bone quality or mechanical stability, within a reasonable time frame. It has been found useful in previous biomechanical studies on human femur fracture fixation.[13,15] All specimens were sprayed with saline throughout testing to prevent drying. Output data were acquired at a rate of 128Hz. All biomechanical tests were video recorded.

*Data analysis and statistics*

Outcome measures included the following:

- The initial bending stiffness (N/mm) of the bone-implant construct was derived from the ascending linear slope of the load-displacement curve in the third loading cycle between 7N and 9N of applied load. Initial stiffness was calculated after 3 cycles to account for specimen/setup settling effects.

- The number of cycles to reach 1mm, 2mm, 5mm, and 10mm of transducer displacement.
- The mode of construct failure was evaluated and recorded for each specimen.

Statistical analyses were performed using R statistical software (R Foundation for statistical computing, Vienna, 2016) The parameters 'initial bending stiffness' and 'number of cycles to 1/2/5/10mm' were analyzed using a linear mixed model containing both fixed and random effects. The Akaike information criterion (AIC) was used for model selection. The factors incorporated in the fixed part were 'plate group' (LatLCPnl, LatLCPl, DorsLCPnl, DoubleLCPl), 'Parameter' (initial bending stiffness, number of cycles to reach 1/2/5/10mm), and the 2-way interactions between these factors. A random intercept for 'cat' (40 hemipelvis from 20 cats) and 'side' (left or right) was added to take the correlation within each cat into account. Normal distribution of the response variables within each model was assessed with PP and QQ plots. In the case of significant interactions between factors, post hoc T tests were used to calculate the P values for specific effects of interest. The Benjamini and Hochberg False Discovery Rate procedure was used to correct for multiple testing.[14] $P<0.05$ was considered statistically significant.

## Results

Initial construct stiffness was higher for the DoubleLCPnl group compared to all other groups. The LatLCPnl and LatLCPl were more stiff than the DorsLCPnl (Fig 3), (Table 1).

The number of cycles to 1mm, 2mm and 5mm displacement were higher for the DoubleLCPnl group compared to all other groups (Table 1). The DoubleLCPnl group showed a higher number of cycles to 10mm displacement compared to both single non-locking systems (DorsLCPnl and latLCPnl) (Table 1). However, no difference was found between the DoubleLCPnl and the latLCPl groups for 10mm displacement. Furthermore, more cycles to reach 5mm and 10mm displacement were found for the LatLCPl compared to the LatLCPnl group (Table 1). More cycles to reach 10mm were found for the LatLCPl group compared to the dorsLCPnl group (Fig 4).

The LatLCPnl failed exclusively by screw loosening; in contrast, this mode of failure was not observed in the LatLCPl group, which failed exclusively by bone slicing (ovoid enlargement of the hole caused by the fixed screws cutting the bone) (Fig 5). Bone fracture was the most common mode of failure for the DoubleLCPnl. In the DorsLCPnl group, implant bending was most commonly encountered. In all groups except for the LatLCPl group screw loosening occurred (Table 2). After biomechanical testing, in the LatLCPnl group all screws were judged to be loose in all specimens, except the screw purchasing the sacrum.

## Discussion

In this study evaluating plating techniques for comminuted ilial fracture in cats, a double plating construct was the stiffest construct and had a higher resistance to fatigue failure than all other plating groups, with the exception of the single locking construct. These results partially confirm our first hypothesis. The locking plate constructs performed similarly to the double plated constructs in cycles to 10mm displacement; however, no significant differences were found when comparing the single plated constructs at 1mm and 2mm displacement. We reject our second hypothesis, because the locking plate constructs were superior to the lateral non-locking construct only at 5mm and 10mm displacement and to the dorsal plated constructs at cycles to 10mm displacement.

The high construct stiffness of the DoubleLCPnl is consistent with previous studies evaluating double plating in long bones in veterinary and human medicine.[16 -19] A mechanical study evaluating orthogonal plating and plate-rod constructs in a canine tibial fracture gap model found a significantly higher stiffness and higher failure loads for the orthogonal plated specimens.[19] Similar results were also found in a biomechanical study comparing axial construct stiffness of orthogonal plates to a single lateral bone plate in periprosthetic femur fractures in people.[18] The effect of orthogonal plates on mechanical properties of the construct is multifold. First, plate screws can be inserted in two planes, increasing screw purchase and decreasing the risk of screw pullout. Second, applying orthogonal plates allows better control of the multidirectional forces acting on the fracture fragments, as one of the two plates may always be loaded in tension. In addition, one of the plates is always aligned with its width to the bending direction, resulting in a greater area moment of inertia.[20,21] Therefore, in case of a comminuted ilial fracture in a cat, orthogonal plating may be particularly advantageous because of the increased screw purchase in the small caudal bone fragment and the thin ilial wing and the superior biomechanical strength.

The higher stiffness values and resistance to cyclic fatigue of the locking plate compared to the single non-locking plate constructs at higher displacements (5mm and 10mm) could be explained by the locking mechanism. A locking plate acts as a single beam construct because motion at the plate-screw interface is eliminated. This mechanism decreases the risk of screw pull out and screw loosening. [22-25] The advantage of locking plates may be more evident in the feline ilium compared to appendicular bones, because only screws with a short working length can be inserted in the narrow ilial bones. As demonstrated in a human study evaluating pullout strength of cervical screws, resistance to screw pullout is directly proportional to screw working length.[26] Dorsal plating offers the advantage of using longer screws, which may explain the lower rate of screw loosening in this study and the reported lower rate of screw loosening in clinical cases when compared to lateral applied non-locking bone plates.[5] Despite these possible advantages, we found that the LatLCPl was significantly stronger compared to the DorsLCPnl at cycles to 10mm displacement, emphasizing the benefits of locking constructs. Also the higher cycle numbers to 5mm and 10mm comparing LatLCPl to LatLCPnl underline the advantages of locking implants in the feline ilium.

Screw loosening was observed in all non-locking constructs, consistent with clinical studies reporting a high incidence associated to non- locking plates.[4,10] It is interesting to note that the sacral screw in the lateral plating group using non-locking screws never loosened. This is likely explained by its longer working length. In the DorsLCPnl group, plate bending was the typical mode of failure. This is in contrast to the reported clinical cases where no plate bending occurred.[5] In our model the caudal fragment was loaded axially. In order to mimic the naturally occurring loads more closely, the specimen was rotated, as described above, to account for the medially directed loads occurring at the hip joint. Nevertheless, in the dorsal position, the bending direction is aligned with the thickness of the plate in the predominantly axial loading. This also explains the higher initial stiffness when comparing the LatLCPnl to the DorsLCPnl.

Several limitations should be considered when considering our results. First, ex vivo mechanical test do not replicate in vivo conditions. Cantilever bending and a single loading direction were selected as the most significant testing methods to evaluate fixation of feline ilial fractures. This testing set up is supported by the dorsal and medial displacement of the caudal fragment noted during testing, resembling the typical clinical scenario in case of screw loosening and loss of reduction.[4,10] Another limitation is that the gap model used in this study does not represent the most common fracture type of the feline ilium, which are simple or minimally comminuted fractures.[2] In this study a comminuted fracture model with a 3mm transverse gap ostectomy was selected to simulate the worst-case scenario, with limited screw purchase and small fragments. Even if not observed in this study, the small gap may have allowed contact between the two fragments during caudal fragment subsidence, creating a more stable situation during cycling. Additionally, other described methods of plating small ileal fracture fragments, including T-plates, double plates on the lateral aspect, composite fixation, or long plates extending over the acetabulum were not tested in our study.[10,11,27,28] It is unknown if these techniques would have performed similarly to the single locking implant on the lateral aspect. The choice of the implant group was made to include a broad range of techniques, but it should be considered that some surgeons may not use single plates for comminuted fractures, and that double plating may lead to stress protection. A methodological limitation is that stiffness was measured within only the third cycle. Averaging the stiffness values over more cycles would most probably reveal more accurate values, considering the response of biological tissue upon mechanical loading, as well as the variances derived by the embedding. However, the differences between the groups were considered evident enough, and therefore only the third cycle was reported. Another limitation that may have affected the results is the lack of bone density measurements.

In conclusion, single locking plates are biomechanically superior to non locking plates in a feline ilial fracture gap model in this vitro study. These results can be explained by the increased fatigue life and resistance to screw loosening of locking plates. Thereby, complications such as screw loosening and pelvic canal narrowing might be avoided when using locking plates in feline comminuted ilial fractures. Double plating with non locking implants may be selected in cases where higher loads and slower healing is expected. However, our results should be interpreted carefully when considering the physiologic loads occurring in a cat at walk. In the current literature peak vertical forces of 38-50% of body weight in the hindlimbs of cats are described during walk, resulting in a load of approximately 12.5N per hindlimb in an average size cat. The lowest failure load observed in the treatment groups was 90 N, more than 6 times the normal peak vertical force of a single limb. Future studies should evaluate our recommendations in a clinical set up.

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